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Catoca Diamond Mine – Implementation of an Advanced Monitoring Network for a Tailings Storage Facility (TSF)

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Abstract

Catoca mine is an open-pit diamond mine belonging to Sociedade Mineira do Catoca in Angola that began in 1995. It has a large active tailings storage facility (TSF) and two smaller deactivated TSFs. Catoca aims to comply with Global Industry Standard on Tailings Management (GISTM) and has installed a comprehensive monitoring and fully automated control network infrastructure that is connected to a database and dashboard viewed by operators and managers. This interactive database can be accessed anywhere in the world. The enhanced monitoring network can be used in analysing the causes of TSF failures and providing early warnings for prevention of failures.

Keywords: Tailings Storage Facilities, Monitoring, Automation, Pore Pressures, Dam Failure, Diamond Mine

Introduction

Catoca mine is an open-pit diamond mine belonging to Sociedade Mineira do Catoca in Angola which started in 1995. The mine is in the Province of Lunda Sul, 1050 km east of Luanda(Capital of the Republic of Angola), very close to the border with the Democratic Republic of Congo (DRC). It has a large active tailings storage facility (TSF) and two smaller deactivated TSFs.

The pit is next to the Lova river, which drains to the North into the Tshikapa River which joins the Congo River then drains into the Atlantic Ocean through the DRC. The active TSF is on the Lupugo and Luite streams that join the Lova downstream of the main TSF wall. Fig. 1 shows the mine location, the main rivers, and the catchment area for the main TSF.

Catoca processes kimberlite ore to extract diamonds and has a large active tailings storage facility (TSF) and two smaller deactivated TSFs. The three TSFs are shown in figure 2.

Catoca is the largest of all kimberlite pipes in the Lucapa kimberlite structure in northeastern Angola, covering a surface area of about 64 hectares. It is the fourth largest known kimberlite. The pipe comprises volcanogenic-sedimentary rocks. The inner ring of the vertical pipe comprises porphyritic kimberlites, while the centre is primarily kimberlitic breccias. The type of kimberlite is relevant to the mineral processing method as the high clay content results in a high concentration of suspended sediments in the tailings pond, giving it its characteristic red colour.

The pipe is intruded into Archaean granite-gneisses and crystalline schists, overlain by Palaeogene to Neogene sands of the Kalahari Formation some tens of metres thick. A small kimberlite pipe to the southwest of the main pit has been mined out. The TSFs sit on Kalahari sand and weathered granites, gneiss and schists.

Groundwater levels are from 5 to 30 m deep, the aquifers are weathered rock, alluvium, and some fracture/fault structures.

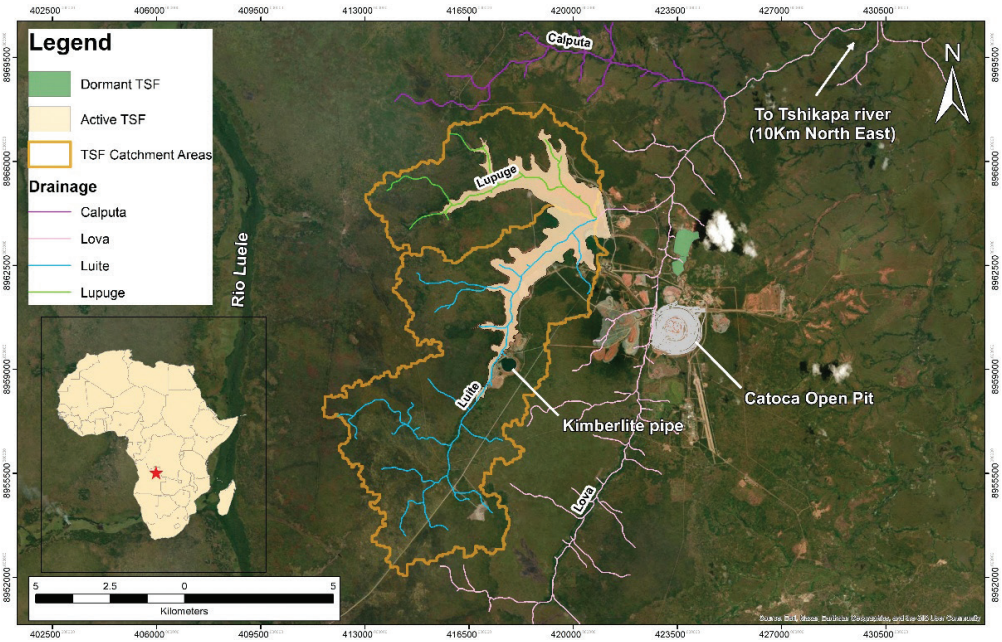

Figure 1 Catoca location and drainage.

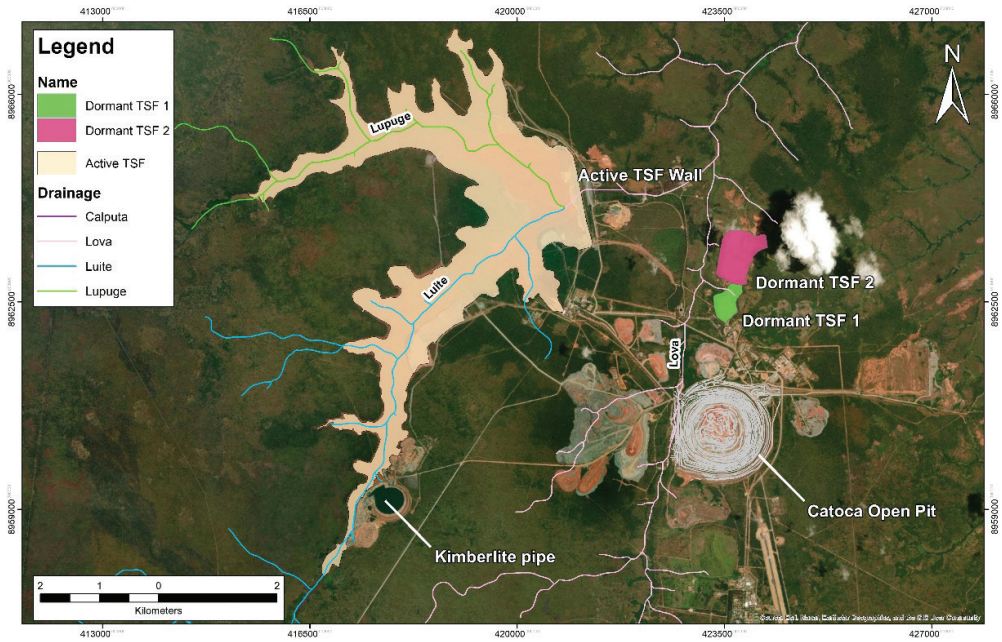

Figure 2 Three tailings storage facilities.

Monitoring objectives

Sociedade Mineira do Catoca, the owners of Catoca Diamond Mine, are working hard to become compliant with the Global Industry Standard for Tailings Management (GISTM 2020) (globaltailingsreview.org) and to meet recommendations listed in Morton *et al* (2020). Mine management are very aware of causes of failures of TSF installations worldwide. The failures are predominantly caused by excess and uncontrolled water (Shahid *et al* 2020) in the pond and in the dam walls. Over the last three years, Catoca has installed a comprehensive monitoring and control network infrastructure to monitor all aspects of the dam morphology. The Catoca system is fully automated and connected to a database-enabled dashboard which is viewed by operators and management at remote workstations. This bespoke interactive database can be accessed anywhere in the world and has also been designed to inform engineers, shareholders and stakeholders. With this interactive database, Angola now has an enhanced monitoring network capable of reducing risk by monitoring all aspects of the water and materials balance, analysing the causes of TSF failures and providing early warnings to enable risk reduction and prevent failures.

Historically, monitoring of TSFs around the world has tended to concentrate on the simple measurement of movement of the TSF dam wall. This is reactive monitoring; once unplanned movement of the dam starts it is too late to stop it. Catoca is proactive in its approach as it measures the inputs and outputs of the TSF (water and materials), interprets potential causes for movement of the TSF, sets targets for water control and then implements the required mitigation measures timeously.

Catoca TSF complex comprises three TSFs. Two dormant TSFs were commissioned in the 1980s and closed in the 1990s. These reach an elevation of 970 mamsl. The active TSF was started in 2000 and covers 1280 hectares and reaches an elevation of 950 mamsl. Fig. 3 shows the detail of the two dormant TSFs.

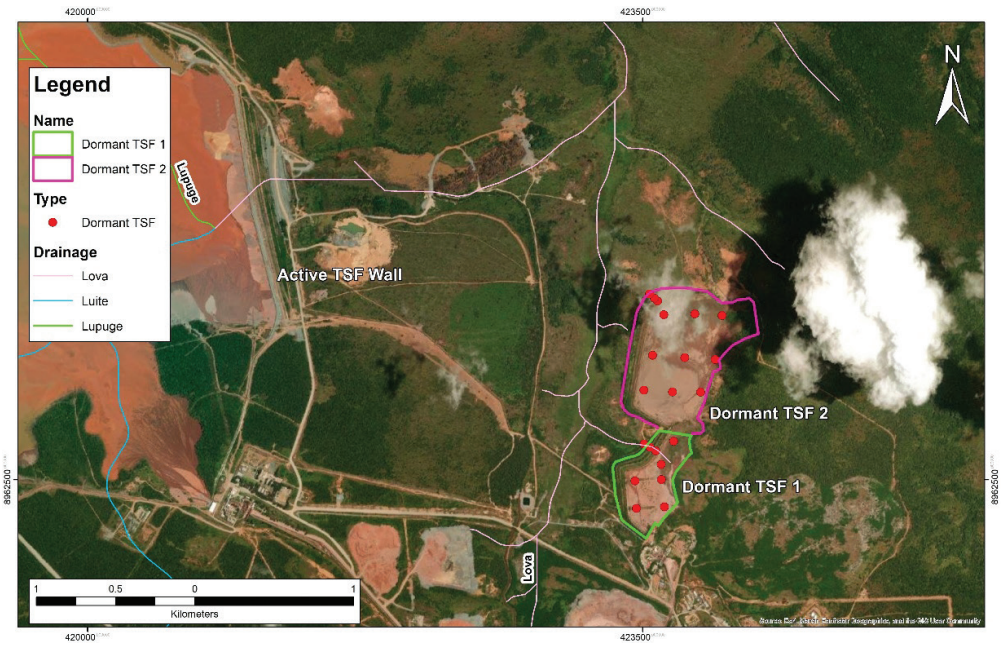

Figure 3 Two dormant TSFs with vibrating wire piezometers.

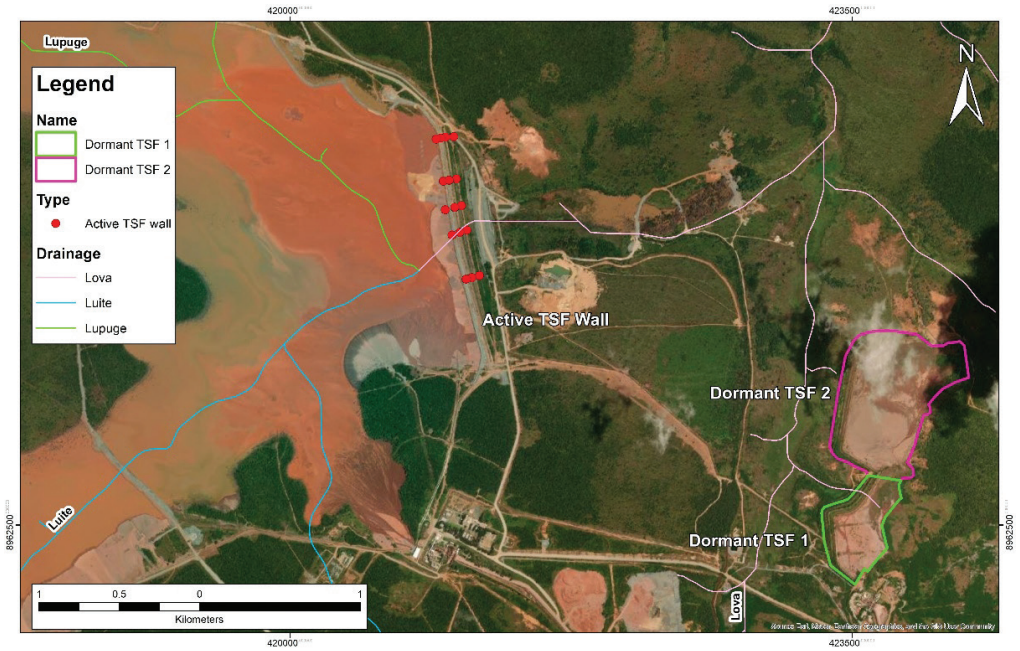

Figure 4 *Active TSF with vibrating wire piezometers.*

Description of monitoring network

Catoca collects data, collates it into useful information (graphs, cross-sections and tables), then interprets this information to generate knowledge, which is then used to manage the TSFs and reduce risk. Surface water levels and groundwater pressures are measured using Vibrating Wire Piezometers (VWP's), both sealed and suspended. Inclinometers are used to observe movement in the TSF wall.

Catoca's tailings team, working with TecWise Africa (https://www.tecwiseafrica.com) has installed:

- Three weather stations to measure rainfall.
- Twenty-two grouted and sealed vibrating wire piezometers in the active TSF to monitor the pore pressure and water levels in the wall of the TSF.
- Fifteen vibrating wire piezometers (suspended) in the dormant TSFs to monitor water levels in the dormant TSFs.
- Twenty-nine open groundwater level monitoring boreholes with suspended vibrating wire piezometers to monitor groundwater levels on the regional scale of the Catoca mine.
- Three inclinometers in the active TSF to measure lateral deformation or displacement of the TSF wall.
- Six water level flumes and sensors for measuring streamflow.

A dashboard system, created by Insight Terra https://www.insightterra.com, and described in Morton and Bovim 2023, is used to display data collected by the instruments. The dashboard displays live information obtained from the weather stations, vibrating wire piezometers and inclinometers. Regular measurements of beach lengths are collected using survey drones and hand surveys of vertical pegs located in the TSF wall, dikes, and beach area.

In cross-section, the active Catoca TSF is also supported by a new buttress, designed by Knight Piesold. Fig. 5 illustrates the profile from beneath the TSF to the main pond along the line of VWPs 8, 10 and 12. The cross-section shows the water levels in the pond, the beach length, the position of the VWP's and the topography.

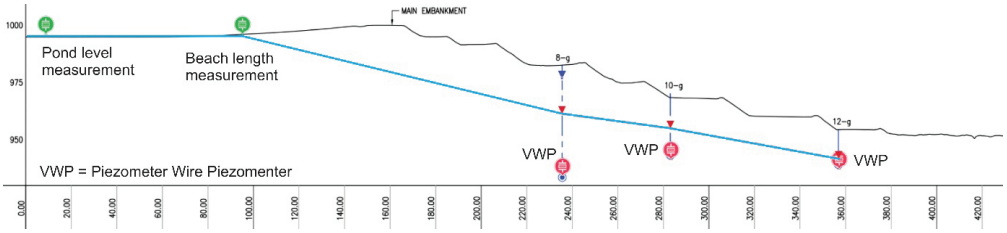

Figure 5 Cross section of TSF profile

All the TSF critical areas are now monitored. The management team can see in real-time dashboards, the health of the TSFs using graphics showing the water level in the pond, the beach length, the pore water pressures in the aquifer below the TSFs, the pore water pressures in the dam walls and dormant TSFs, inclinometer data and also the water balance budget including rainfall inputs and in/outflows from the streams feeding into the TSFs.

The data is collected automatically and then sent via a telemetry network to Insight Terra's platform, where data is automatically consolidated into graphs and cross-sections. This information is then presented as a live dashboard which has been configured to report in English and Portuguese in formats to suit the needs of the operators, managers, designers, and risk management practitioners. Fig. 6 shows the locations of the VWPs' in the Active TSF wall and Fig. 7 is a dashboard presentation of the VWPs' water level readings.

Trigger levels have been established for increases in water levels, the rate of increase and the maximum water levels. These trigger levels are linked to a warning system which ensures timely responses to mitigate risk. Fig. 8 shows the overall layout of the monitoring network, data transmission sites and linkage. The system has battery back-up, as well as solar panels to ensure there is no interruption of service during any power outages.

Conclusions

The implementation of an advanced monitoring network at the Catoca Diamond Mine has greatly enhanced the management and safety of both active and dormant tailings storage facilities (TSFs). By integrating

Figure 6 Locations of the monitoring VWPs in the active TSF.

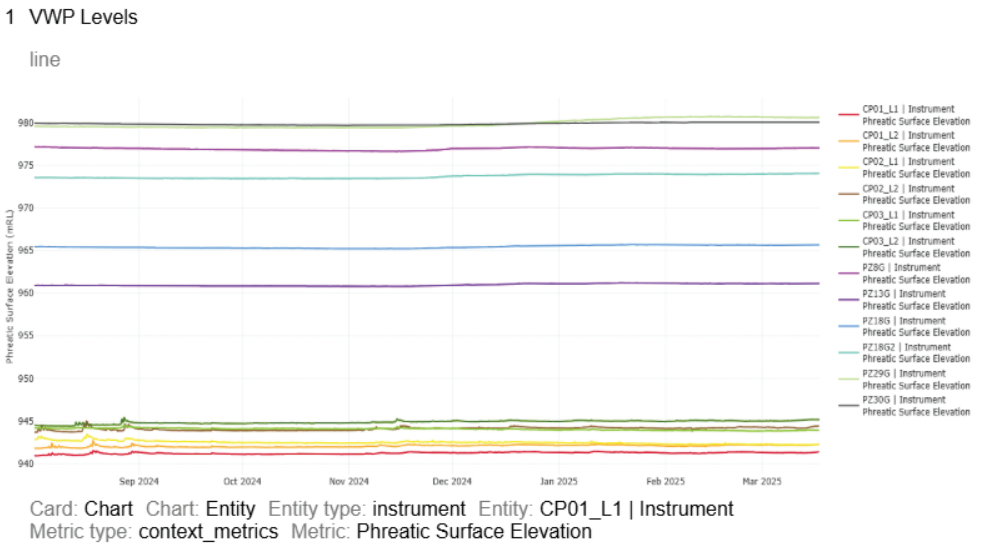

Figure 7 *Water level plots over time for VWPs in the active TSF.*

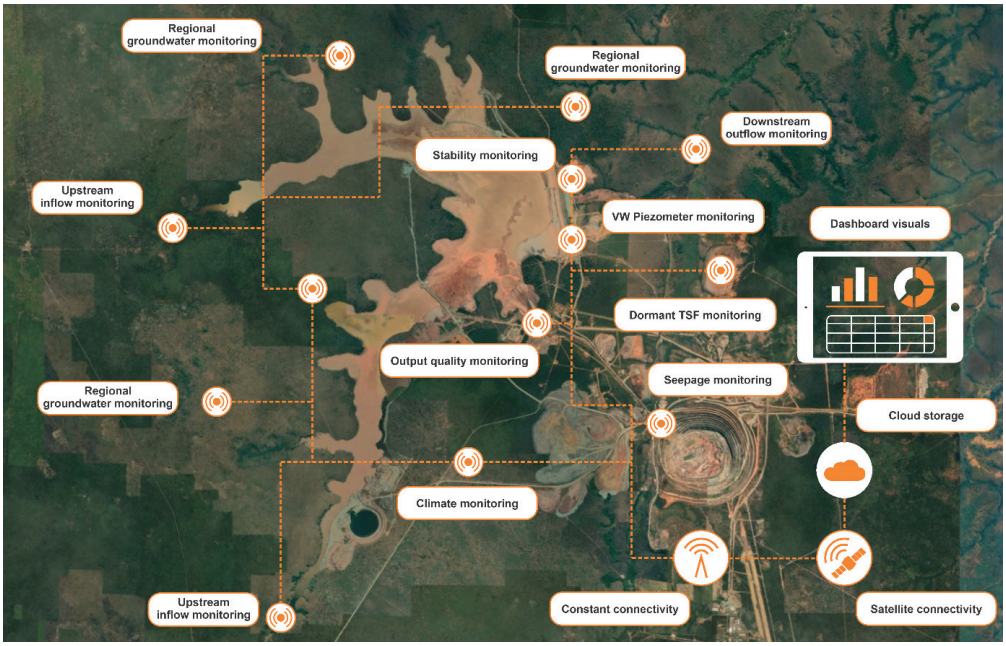

Figure 8 *Schematic of the monitoring infrastructure at Catoca.*

state-of-the-art instrumentation, including vibrating wire piezometers, inclinometers, weather stations, and instrumented groundwater monitoring boreholes, the system provides real-time data on key parameters such as pore pressure, beach lengths, water levels, and structural stability. This data is consolidated and visualised through a live dashboard, allowing operators and management to monitor TSF health remotely and respond proactively to potential risks. The adoption of the Global Industry Standard for Tailings Management (GISTM) principles ensures Catoca's TSF monitoring is aligned with international best practices. The comprehensive network not only reduces the risk of TSF failures, but also serves as a model for other mining operations seeking to enhance their tailings management strategies.

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